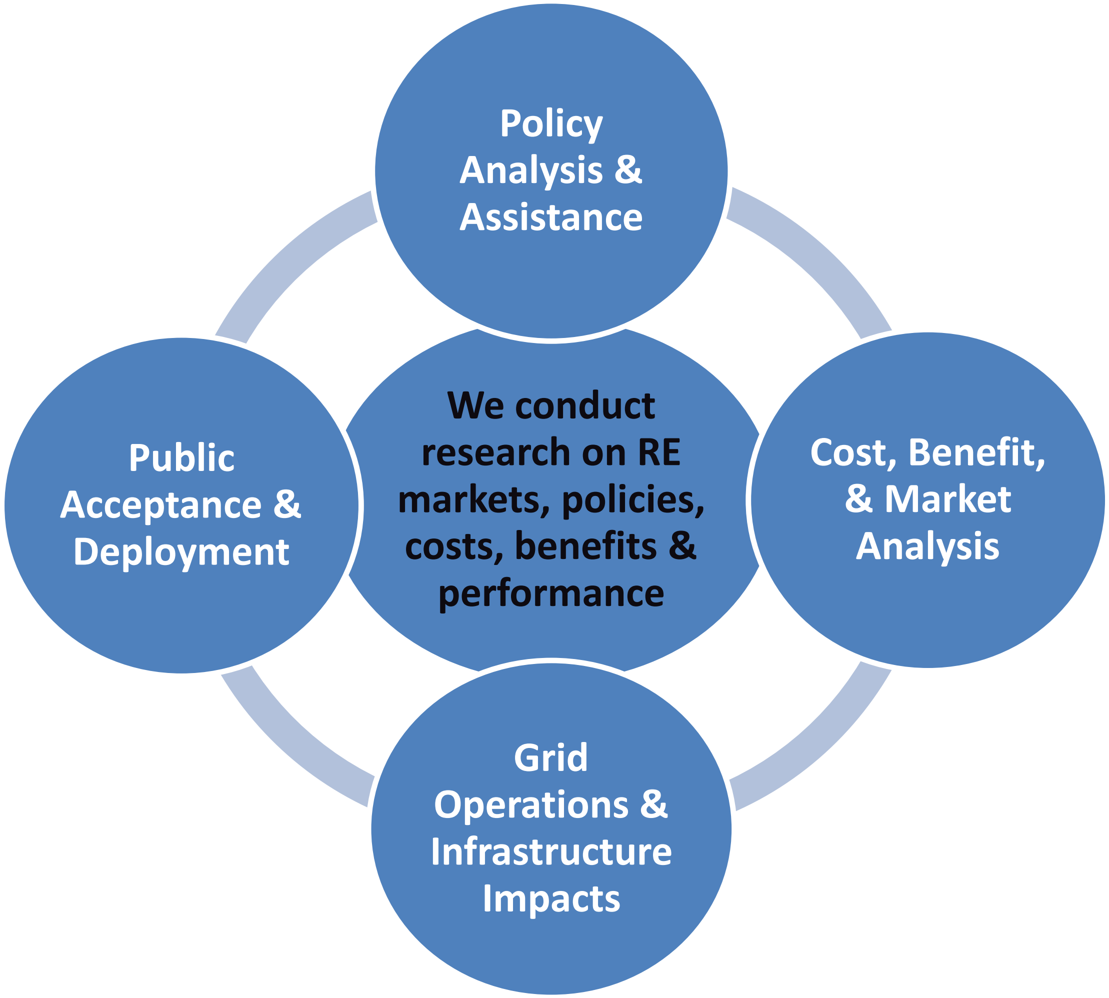
Renewable Energy Research from the Electricity Markets and Policy Group

May 2016

Informing Decision-Makers About the Complexities & Opportunities of Renewable Energy Deployment

Emphasis of Renewable Energy Research in Electricity Markets and Policy Group



Our work in each of these areas focuses on renewable power, with an emphasis on wind and solar electricity

Core Renewable Energy Staff: Electricity Markets and Policy Group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Thanks to our funders at the U.S. Department of Energy: Office of Energy Efficiency and Renewable Energy (Solar, Wind and Water, Strategic Programs, etc.) and Office of Electricity Delivery and Energy Reliability

Four Basic Product Types To Inform Decision-Makers

1. Annual Data and Information Reports
2. Understanding Cost and Performance Trends
3. Other Selected Topical Analyses
4. Direct State and Federal Policy Assistance

Each type of product, and each individual project, has a different intended use and audience

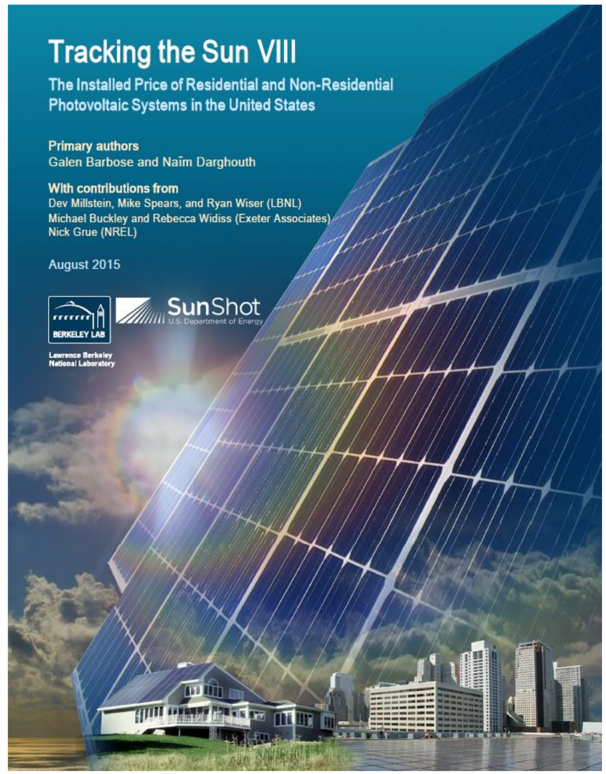
Much of our work, though funded by the DOE, is intended to inform external audiences

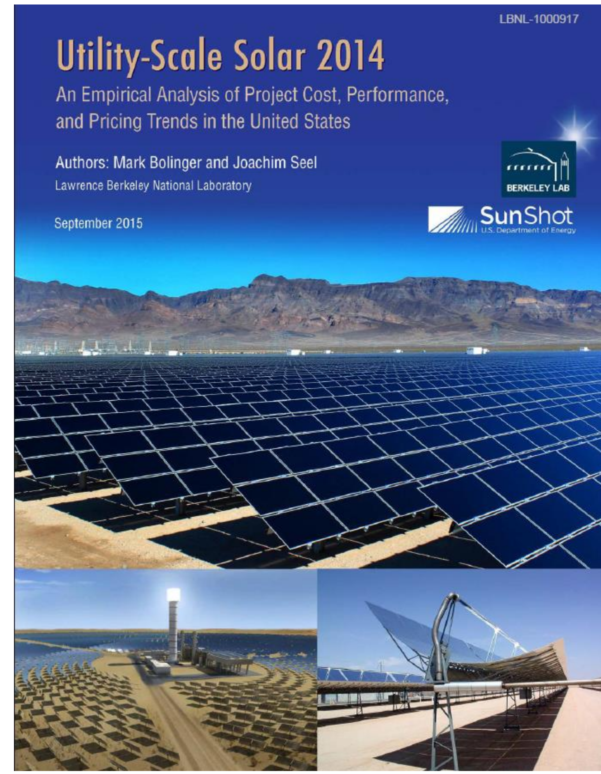
Section 1. Annual Data and Information Reports

Annual data and assessment products directly inform decision-making and provide foundation for additional analytical work inside and outside of the DOE ecosystem

Four Annual Reports: Providing Basic Information to Support Decision-Making

Wind Power	Customer-Sited Solar	Utility-Scale Solar
Since 2007	*Since 2008*	*Since 2013*



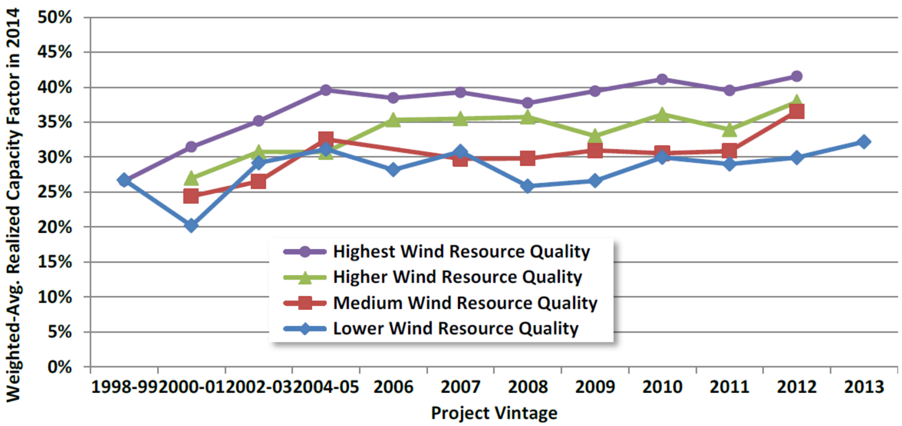


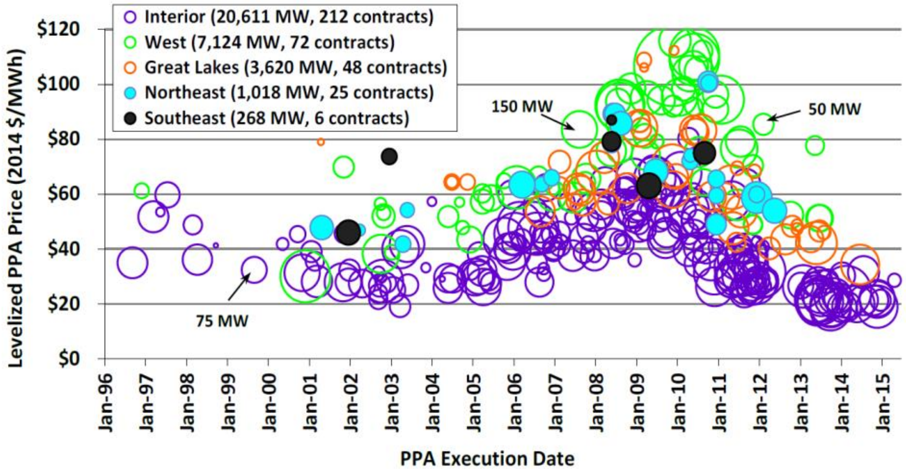
State renewables portfolio standards (RPS): In addition to the three annual reports noted above, LBNL regularly tracks the design and impacts of state RPS policies, with information provided online and through an annual report

Three Wind and Solar Annual Reports

Scope: core focus is tracking cost, performance, and pricing

WIND ENERGY

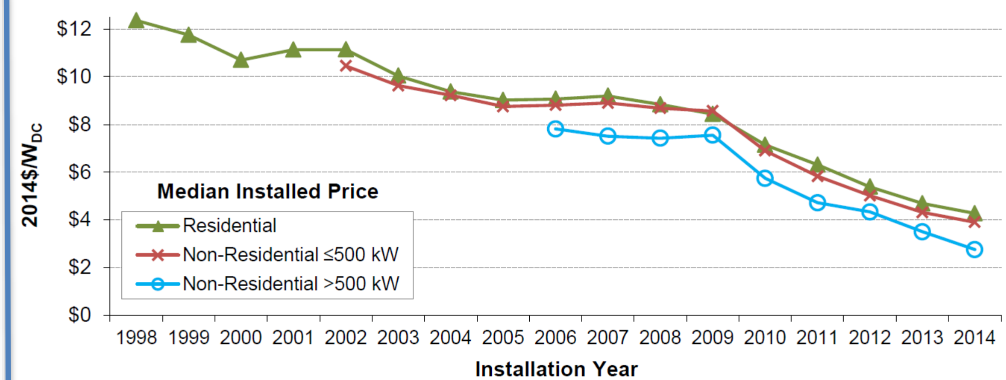




http://windreport.lbl.gov

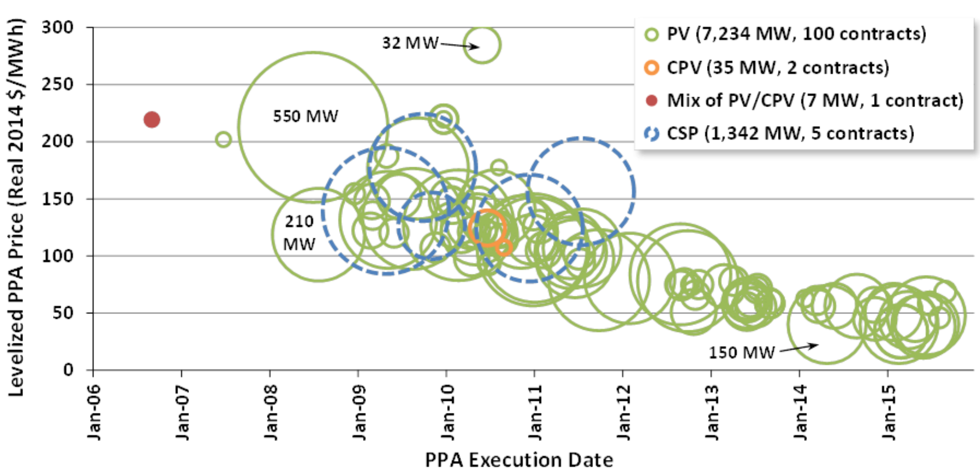
Source: Wiser and Bolinger. LBNL Report. 2015.

SOLAR ENERGY



http://trackingthesun.lbl.gov

Sources: Barbose, Darghouth. LBNL Report. 2015.

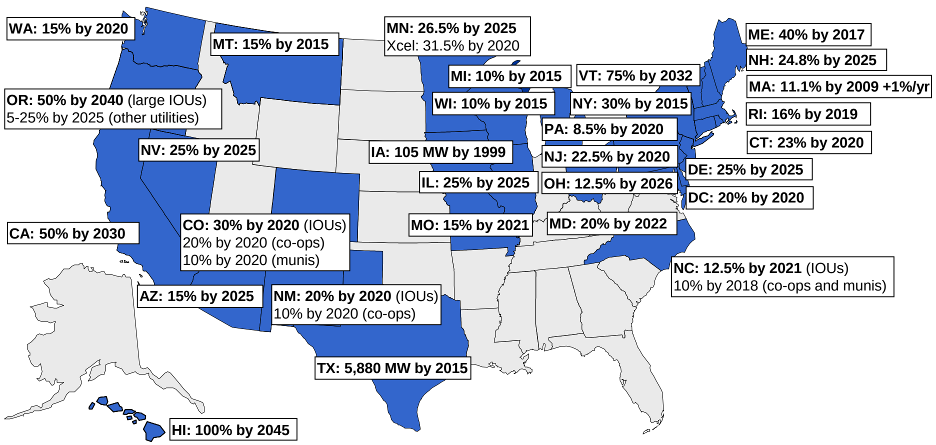


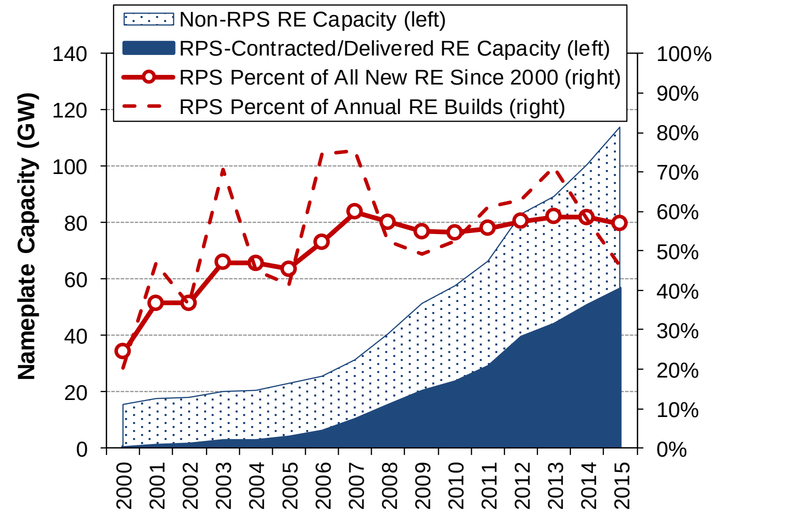
http://utilityscalesolar.lbl.gov

Sources: Bolinger and Seel. LBNL Report. 2015.

State Renewables Portfolio Standards

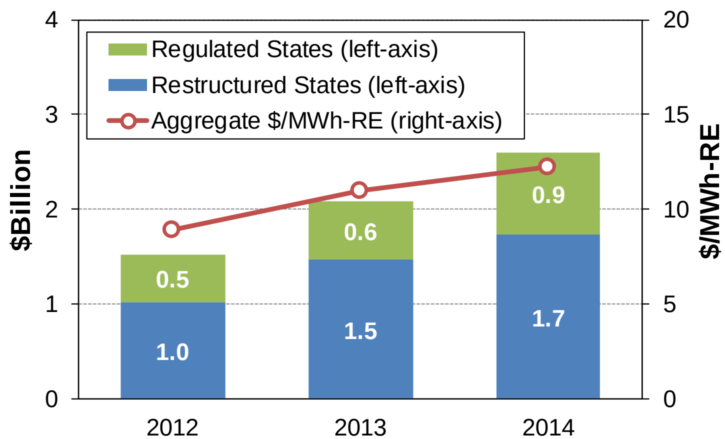
Scope: policy design details, renewable energy demand, compliance results, compliance costs and rate impacts

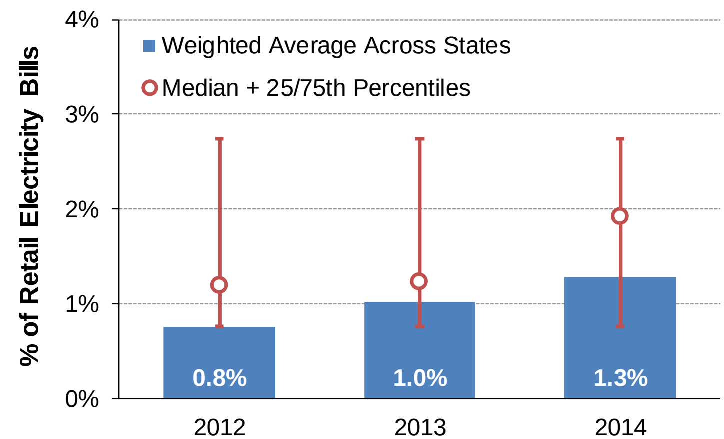




http://rps.lbl.gov

RPS Compliance Costs





Sources: Barbose, G. LBNL Report. 2016.

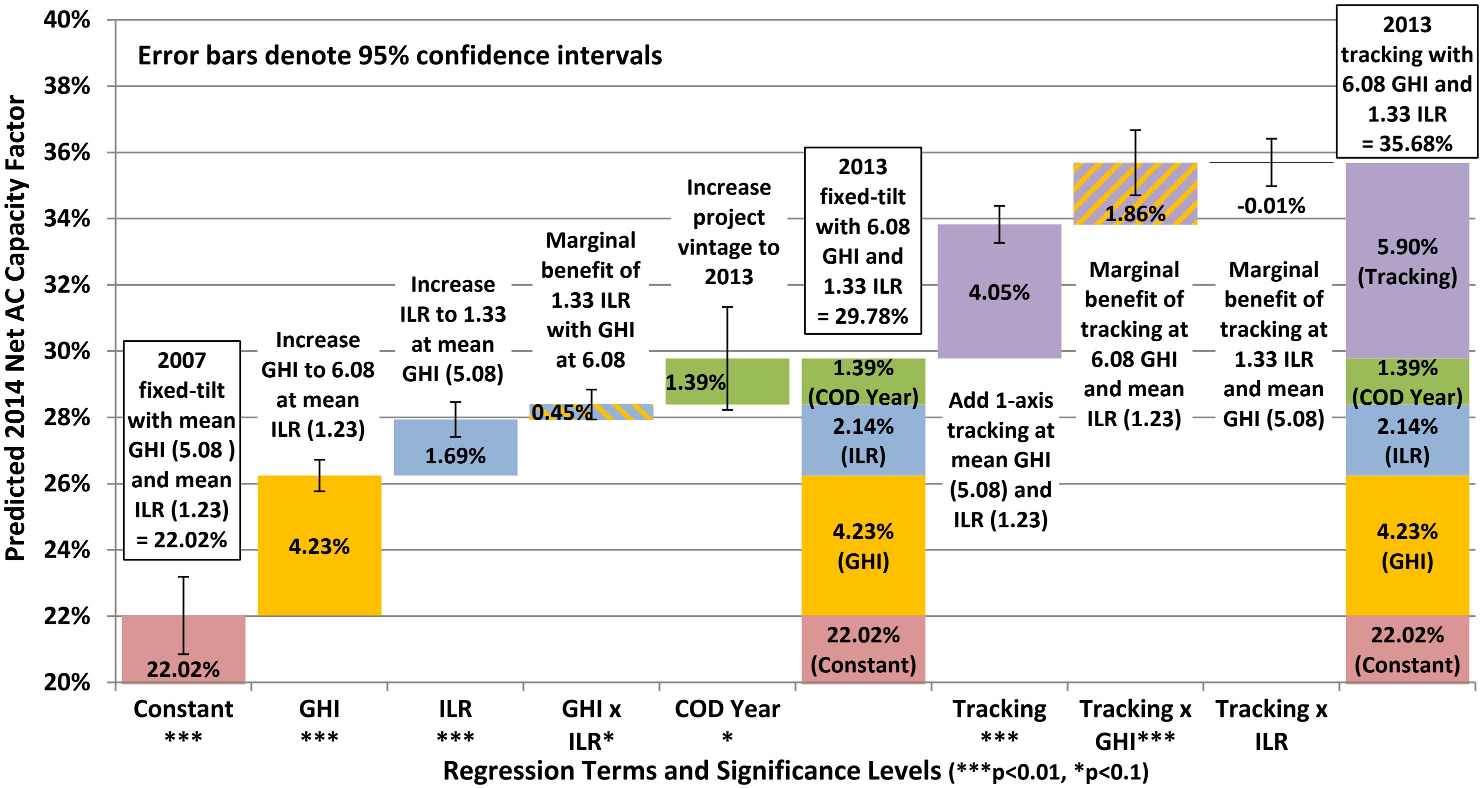
Direct Use of Data from Annual Reports: Examples

- Inform DOE R&D cost targets and progress
  - DOE Wind Program
  - DOE Solar Program
- Inform modeling assumptions
  - Wind Vision study
  - Renewable Electricity Futures study
  - EIA Annual Energy Outlook
  - WECC interconnection-wide transmission planning
  - Many, many more…
- Inform policy and market decisions
  - Benchmark for “reasonable” cost for CPUC CSI program
  - Used in utility resource planning, e.g., NPCC Power Plan
  - Utilities, policymakers, RE industry, academics regularly use data

Section 2. Understanding Cost and Performance Trends *(examples)*

In addition to directly meeting the needs of stakeholders via annual reports, LBNL uses the data underlying the annual reports as a foundation for additional rigorous analysis to inform public debate around renewable energy

Explaining Drivers of Utility-Scale Solar Performance in the United States

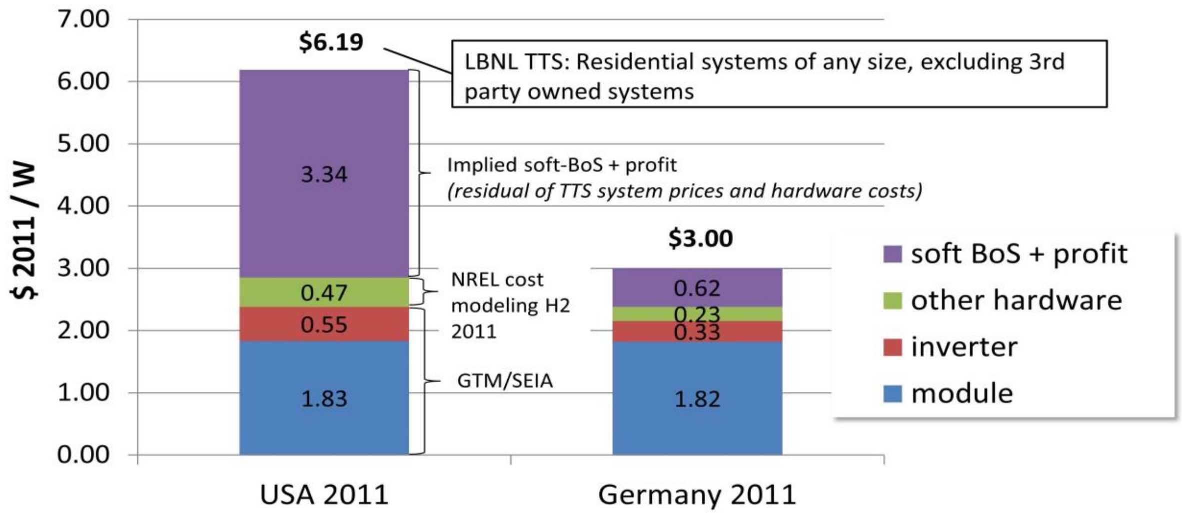


Analyzing the **2014 Net Capacity Factor** (in AC-terms), LBNL conducted the first known multivariate regression analysis of large-scale PV performance

- Looking at all operational projects (>5MW) installed in the United States, the model can explain 94% of observed variation with tight fit
- Largest performance driver is solar resource quality (GHI), followed by the inverter-loading ratio (ILR) and the usage of horizontal-tracking
- Controlling for other effects, younger projects outperform older installations by 0.23% per vintage year (COD)

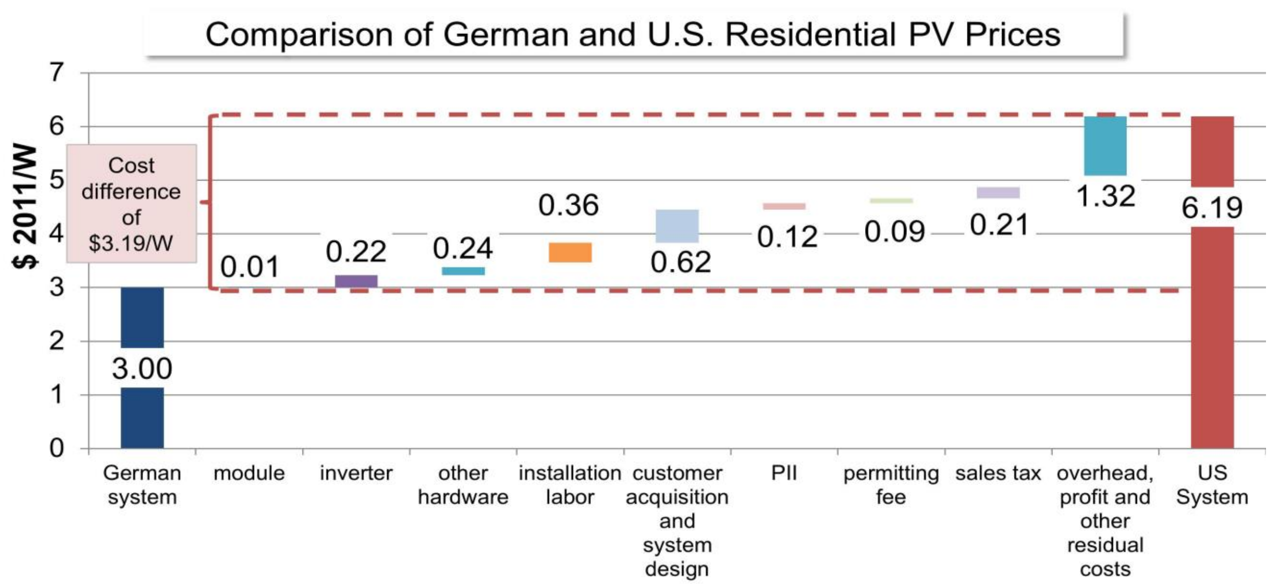
Source: Bolinger, Seel, Wu. LBNL Report. 2016

Germany Demonstrates the Potential for Dramatically Lower PV Costs (vs. U.S.)



Builds on LBNL & NREL collection of data on U.S. residential PV costs, supplemented with surveys of German (and US) PV installers

Illustrates potential for substantial soft-cost reduction in U.S. if German framework conditions can be approached



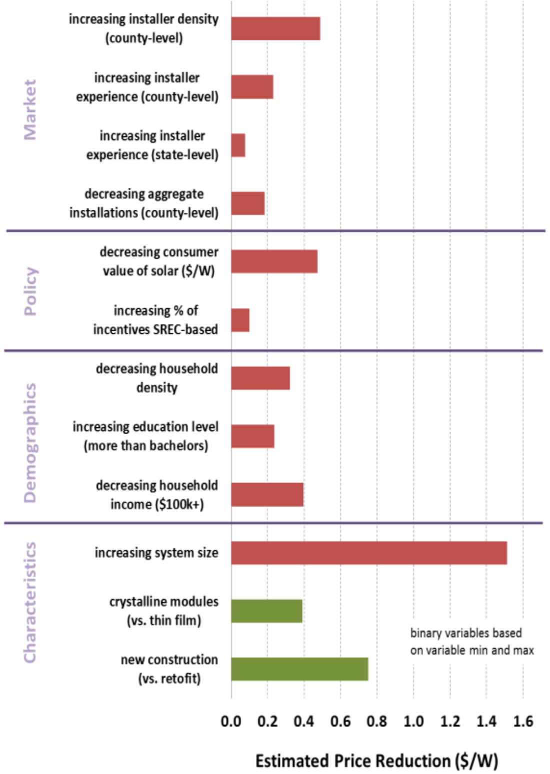
Source: Seel et al. *Energy Policy*. 2014.

Solar Data Analytics / Academic Partners Program

Partner with academics to pursue innovative research that exploits the extensive solar data collected at LBNL, applying econometric tools and focusing on PV cost and market trends

→ **Academic Partners**: K. Gillingham (Yale), G. Nemet (UW Madison), V. Rai (UT Austin)

Lead institution	*Topic*	*Year*
UT Austin	Impacts of permitting practices on PV prices in CA	2013
UT Austin	Incentive pass-through for residential PV in CA	2014
Yale	Investigating drivers for price heterogeneity in PV prices	2014
Yale	Impacts of permitting and regulatory processes on PV prices	2014
LBNL	Project pricing for utility-scale PV	2015
UW Madison	Characteristics of low-priced PV systems	2016
LBNL	Statistical analysis of the performance of utility-scale PV in US	2016
UW Madison	Factors affecting low-priced and higher-priced PV systems	2016 (in prep)
UW Madison	Drivers of price dispersion in PV prices	2016 (in prep)



Notes:
The bars present the pre-incentive price reduction (per watt) from moving from the 5th to 95h percentile of each variable. For green bars , the range reflects the minimum to maximum as these are binary variables. Not all variables are presented in this figure; results for variables on HHI, sales tax, interconnection score, other educational and income variables, local labor cost, customer segment, third-party-owned, tracking, BIPV, battery, inverter and module are found in the full report.

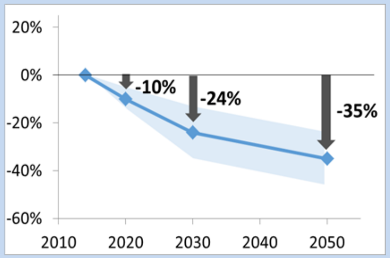
Figure 1. Impact of Various Drivers in Reducing PV Prices

Sources: Dong and Wiser, *Energy Policy*, 2013; Dong et al. LBNL Report. 2014; Burkhardt et al., *Energy Policy*, 2015; Bolinger et al., *Progress in Photovoltaics*, 2015; Nemet et al., LBNL Report, 2015; Gillingham et al., *Energy Journal*, 2016; Bolinger et al., LBNL Report, 2016.

Expert Elicitation: Forecasting Wind Technology Advancement & Cost Reduction

ONSHORE (LAND-BASED)

LEVELIZED COST OF ENERGY (median estimates for median scenario & 1st-3rd quartile range)



DRIVERS FOR COST REDUCTION IN 2030 (median estimates; median scenario)

Capacity factor: +10%
Project life: +10%

CapEx: -12%
OpEx: -9%
WACC: no Δ

TURBINE SIZE IN 2030 (typical projects)

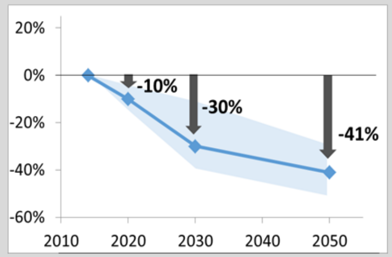
3.25 MW
115 m hub height
135 m rotor diameter

TOP-FIVE IMPACT CATEGORIES

- Larger rotors, reduced specific power
- Rotor design advancements
- Taller towers
- Reduced financing costs
- Component durability / reliability

FIXED-BOTTOM OFFSHORE

LEVELIZED COST OF ENERGY



DRIVERS FOR COST REDUCTION IN 2030

Capacity factor: +4%
Project life: +15%

CapEx: -14%
OpEx: -9%
WACC: -10%

TURBINE SIZE IN 2030

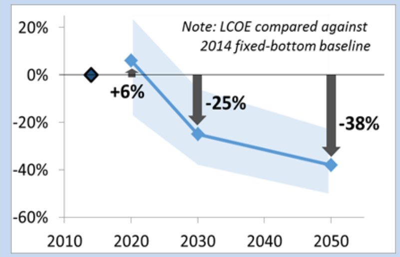
11 MW
125 m hub height
190 m rotor diameter

TOP-FIVE IMPACT CATEGORIES

- Larger turbine capacity
- Foundation / support structure design
- Reduced financing costs
- Economies of scale via project size
- Component durability / reliability

FLOATING OFFSHORE

LEVELIZED COST OF ENERGY



DRIVERS FOR COST REDUCTION IN 2030

Capacity factor: +9%
Project life: +25%

CapEx: -5%
OpEx: -8%
WACC: -5%

TURBINE SIZE IN 2030

9 MW
125 m hub height
190 m rotor diameter

TOP-FIVE IMPACT CATEGORIES

- Foundation / support structure design
- Installation process efficiencies
- Foundation / support manufacturing
- Economies of scale via project size
- Installation / transport equipment

LBNL conducted the largest-known expert elicitation survey (163 respondents) on an energy technology for IEA Wind Task 26, evaluating the:

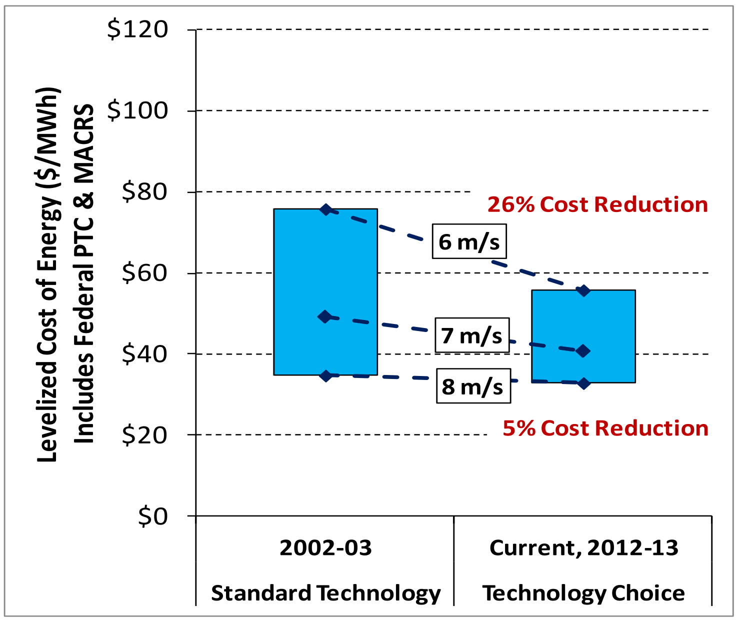
- Magnitude of cost reduction
- Most promising impact areas
- Most effective drivers

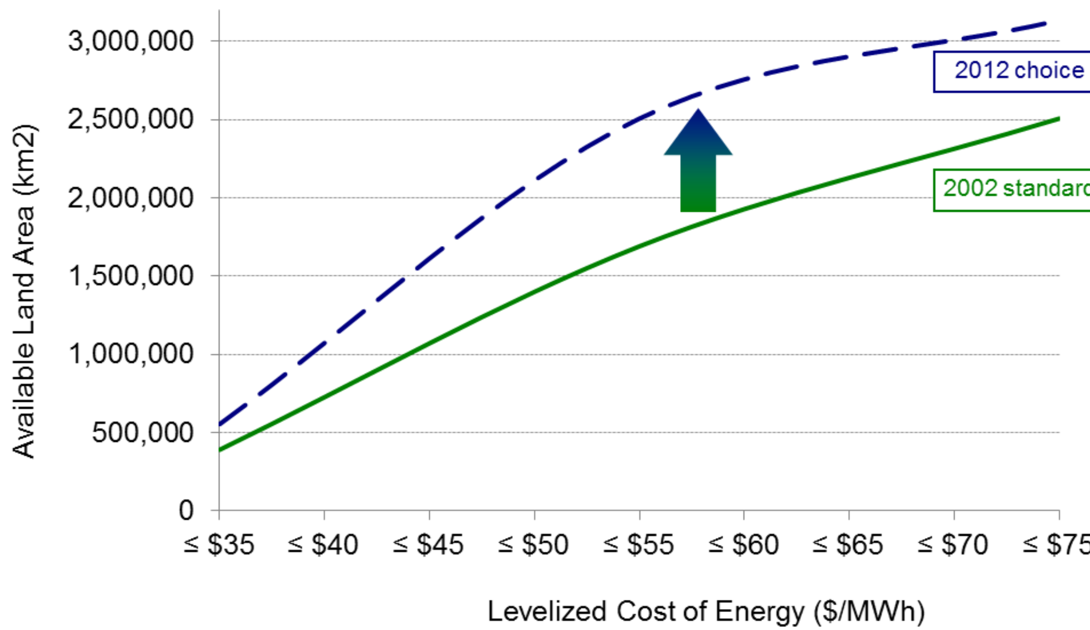
iea wind
NREL NATIONAL RENEWABLE ENERGY LABORATORY
BERKELEY LAB

New Wind Turbine Technology Reducing Cost in Low Wind-Speed Sites

U.S. Wind Power Projects

(with federal tax incentives – PTC & MACRS; modeled data)





Sources: Wiser et al. 2012; Lantz et al. IEA Report. 2013.

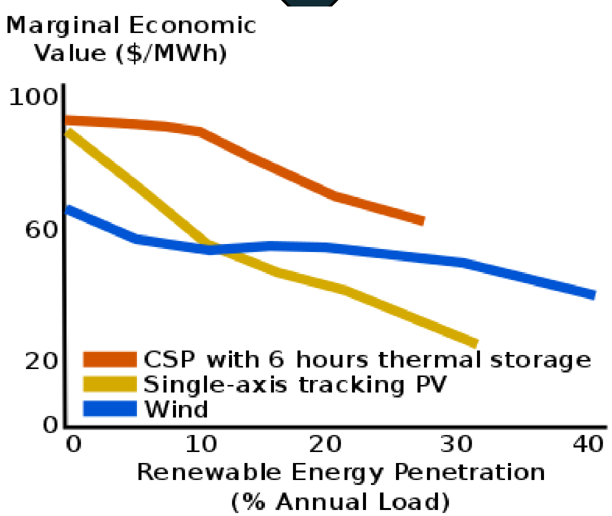
Note: Graphics only include changes in capital cost and turbine design (i.e., capacity factors); graphics do not include changes in O&M, availability, financing, etc.

Section 3. Other Selected Topical Analyses *(examples)*

Meeting the targeted needs of utility stakeholders, renewable energy firms, and local-to-international policymakers with rigorous, objective analysis

Renewable Energy Valuation and Integration: Grid Impacts

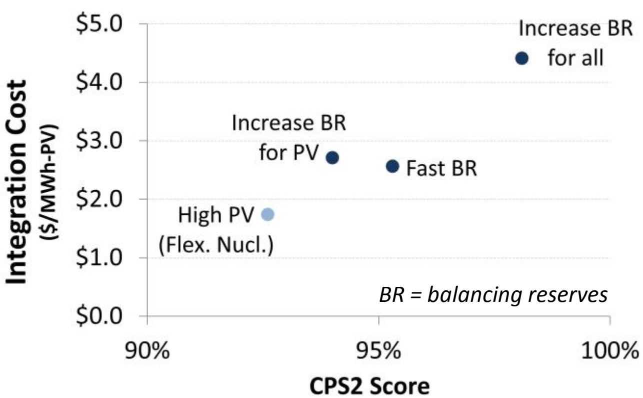
The incremental market value of variable generation changes with penetration. Changes are primarily driven by **energy** and **capacity** value…



... A variety of tools to **increase system flexibility** can be used to partially stem the decline in market value with penetration**.**

Mitigation measure ($/MWh)	Wind penetration 20%	30%	40%
Geographic Diversity	2.5	4.9	10.6
Real-time pricing	3.7	5.0	7.9
Low-cost storage	-0.1	0.4	4.4
Quick-start CCGT	0.3	0.3	-0.6
10% PV	1.1	-1.1	-5.2
10% CSP6	-0.2	-0.6	-4.4

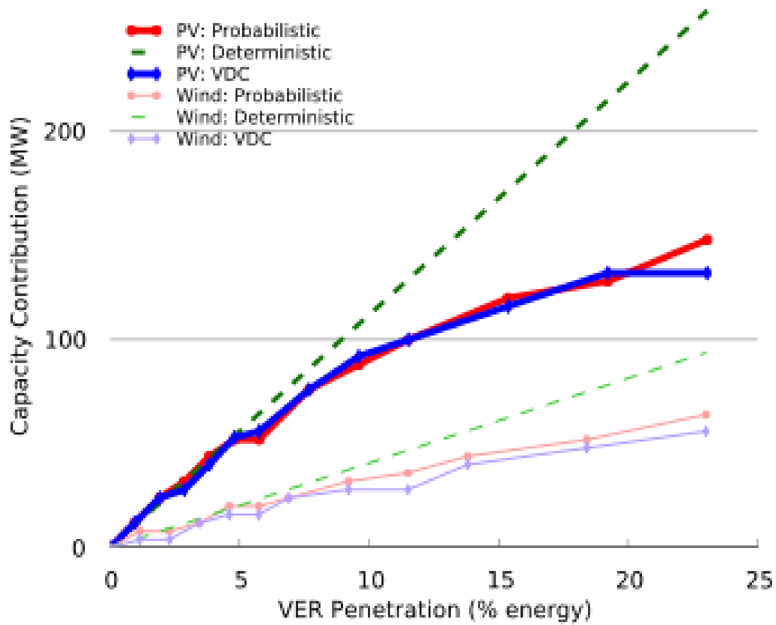
Short-term variability of solar (and wind) is **not** the primary economic concern at increasing renewable penetrations.



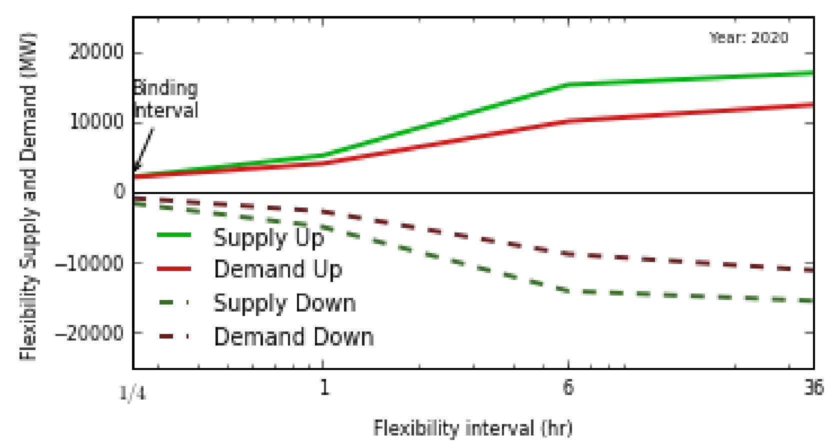
Sources: Mills and Wiser. LBNL Report. 2012.; Mills and Wiser. LBNL Report. 2014.; Mills et al. ANL Report. 2013. Also, Mills and Wiser. *IEEE Journal of Photovoltaics.* 2013.; Mills and Wiser. *Wind Energy*. 2013. Jing et al. *Energy.* 2015

Planning for Renewables: Capacity Value and Flexibility

Full reliability simulations are challenging in capacity expansion models, leading to approximation methods; Sandia/LBNL developed an approach that performs similar to the reliability approach, even at high RE penetrations, without significant computational burden



The "Flexibility Inventory for Western Resource Planners" demonstrates a simplified approach to estimating flexibility supply and demand, applied to IRP resources in LBNL's Resource Planning Portal



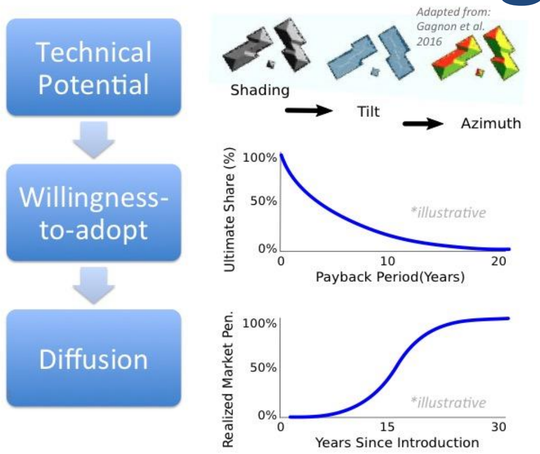
Sources: Munoz and Mills. *IEEE Sustainable Energy.*; Mills and Seel. LBNL Report.2015.

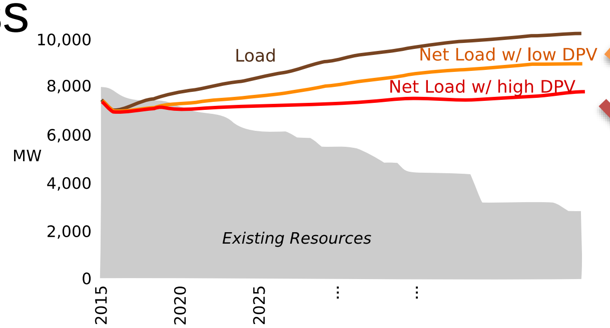
Planning for Renewables: Incorporating Distributed PV in Planning

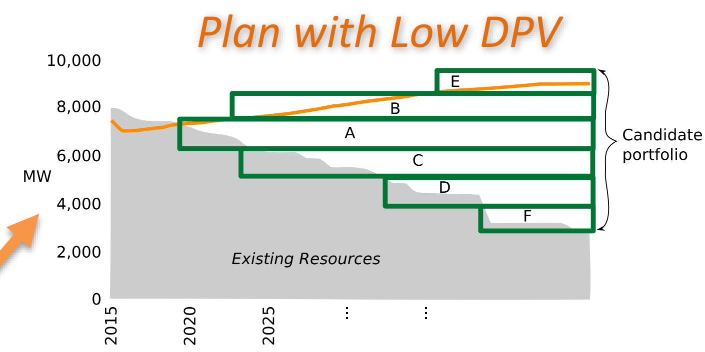
Realizing the full value of distributed PV (DPV) requires that utilities integrate it into planning studies

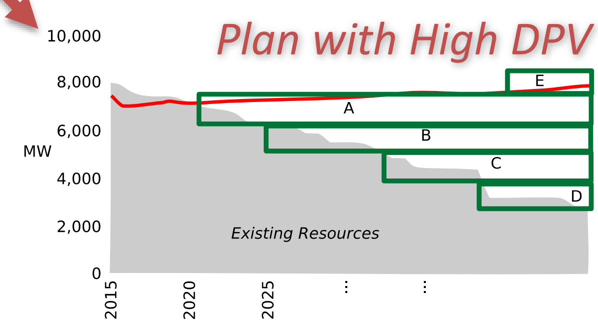
We examined more than 20 resource, transmission, and distribution plans to identify innovative approaches to accounting for DPV in planning studies

The key methodological elements included approaches to creating DPV forecasts, ensuring the robustness of decisions to DPV uncertainty, and considering DPV as a resource option









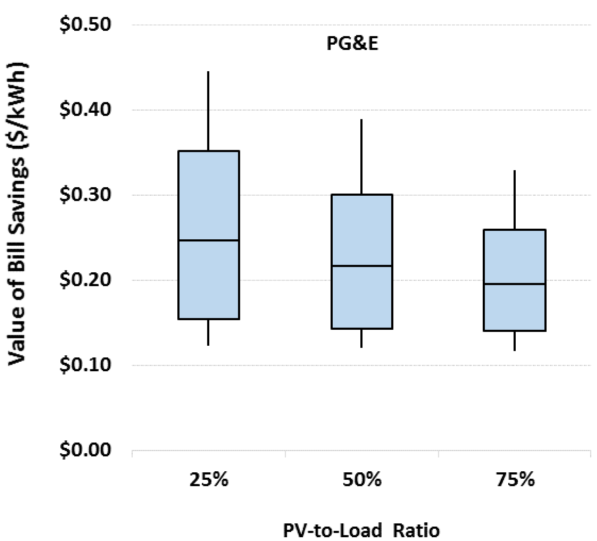
Source: Mills et al. Forthcoming LBNL Report.

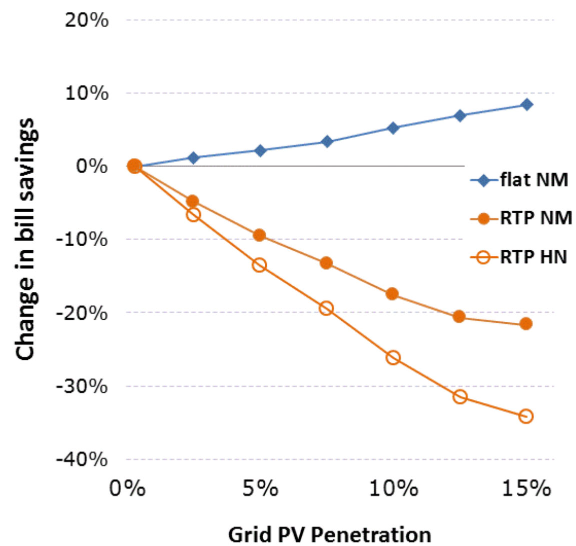
Rate Design Impacts on the Economics & Deployment of Customer-Sited Solar

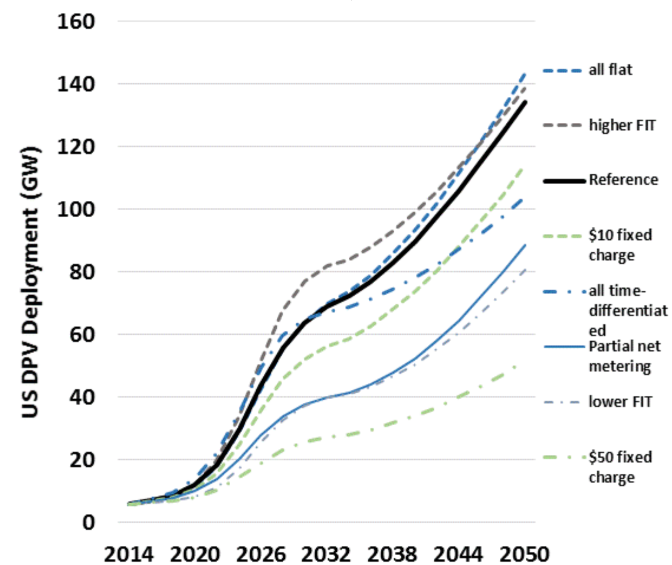
Retail rate design and net metering policies dramatically impact the customer-economics of residential & commercial PV systems.

As **PV penetrations increase**, and under other future conditions, retail rates will change, causing further changes to the customer-economics of PV.

Retail rate design and net metering policies also impact future residential and commercial PV deployment levels.







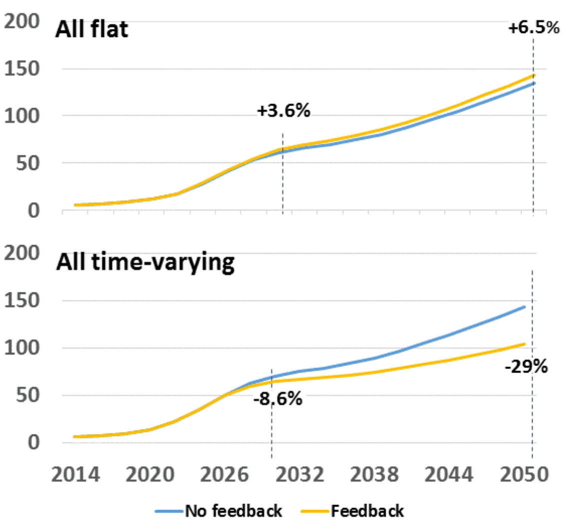
Sources: Darghouth et al. *Energy Policy*. 2011.; Darghouth et al. *Energy Policy*. 2014.; Mills et al. *Energy Policy*. 2008; Darghouth et al. *Applied Energy* 2016.

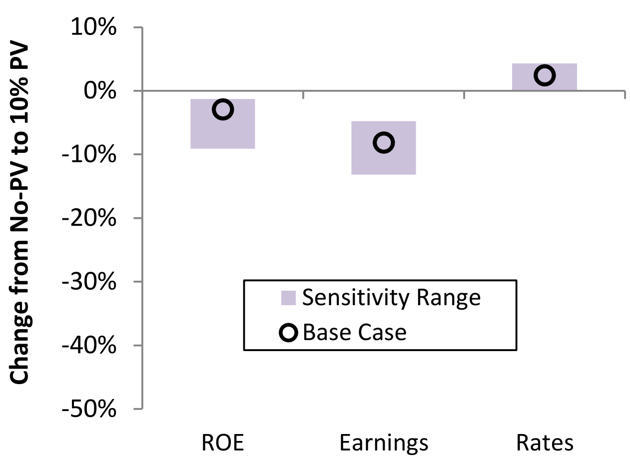
Impact of DG PV on the Traditional Utility Business Model

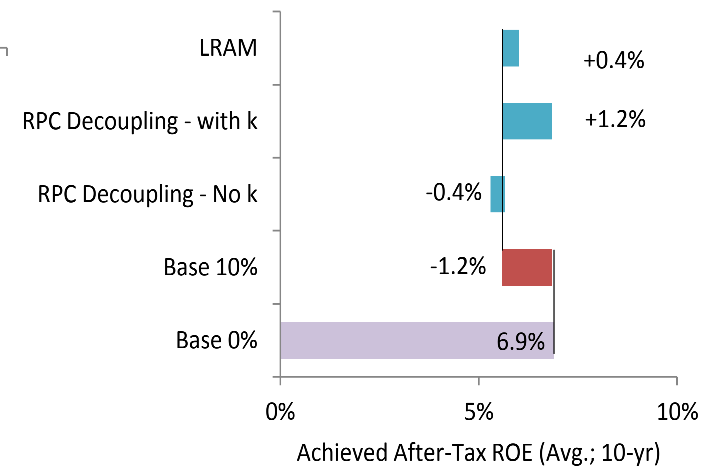
Increased DG PV leads to feedbacks in customer economics that either accelerate or decelerate PV deployment depending on rate design.

Increased DG PV can impact **utility profitability and rates**, though the magnitude of impact depends on utility circumstances.

Increased DG PV can impact **utility profitability and rates**, though multiple approaches exist to mitigate those impacts.







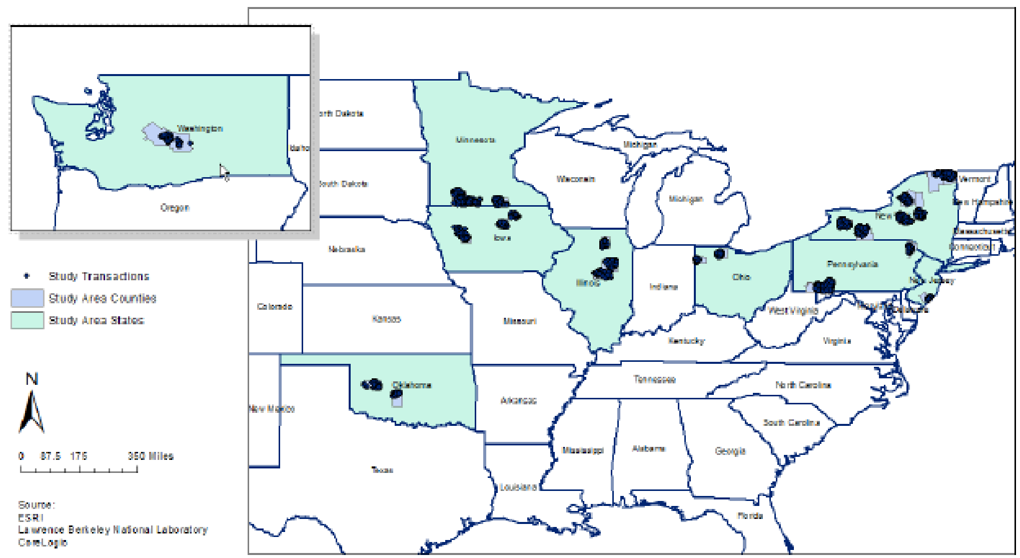
Sources: Satchwell et al. LBNL Report. 2014; Darghouth et al. *Applied Energy* 2016.

Impact of Wind Projects on Residential Property Values

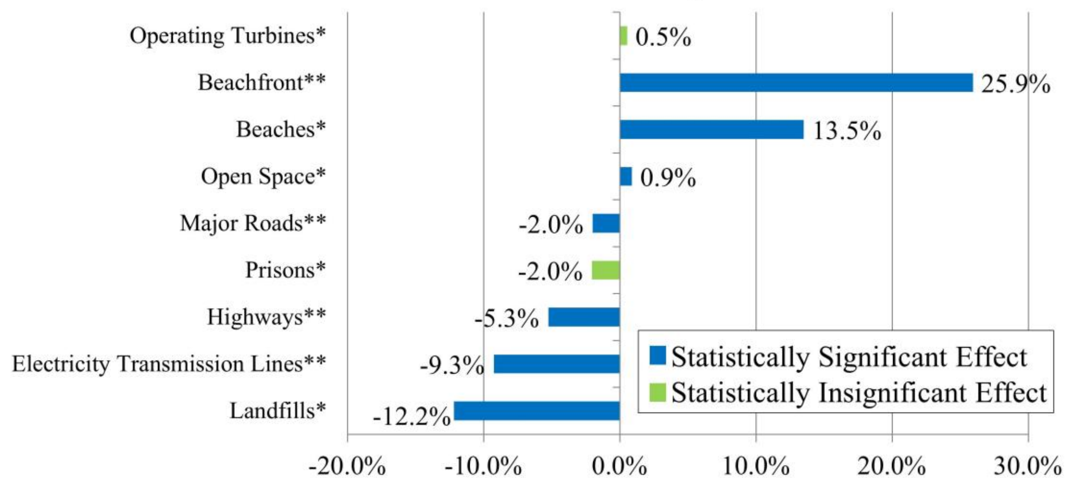
Based on a nation-wide sample (see sample on right) and on a Massachusetts sample (see results on right)…

No statistical evidence that property values of homes located in proximity to turbines have been <u>systematically</u> affected by wind projects

Figure 1: Map of Transactions, States, and Counties



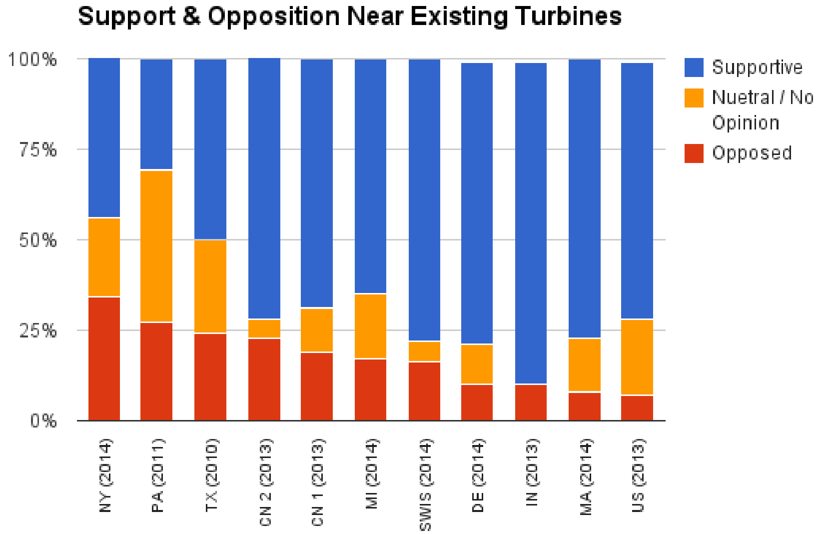
Massachusettes Home Price Impacts



Sources: Hoen et al. LBNL Report. 2013; Hoen et al. LBNL Report. 2014. Hoen et al. *Journal of Real Estate Research.* 2011; Hoen et al. *Journal of Real Estate Research.* 2016.

Baseline Survey Of Residents Near Large Scale Wind Installations

Although a number of US studies have found high levels of support near turbines (see figure), none are transferable to the full population of residents



Other questions also remain:

- Levels of stress and annoyance near turbines?
- Drivers for support or opposition?
- Comparative impacts to other energy/infrastructure sources?
- Changes over time as people move into area?

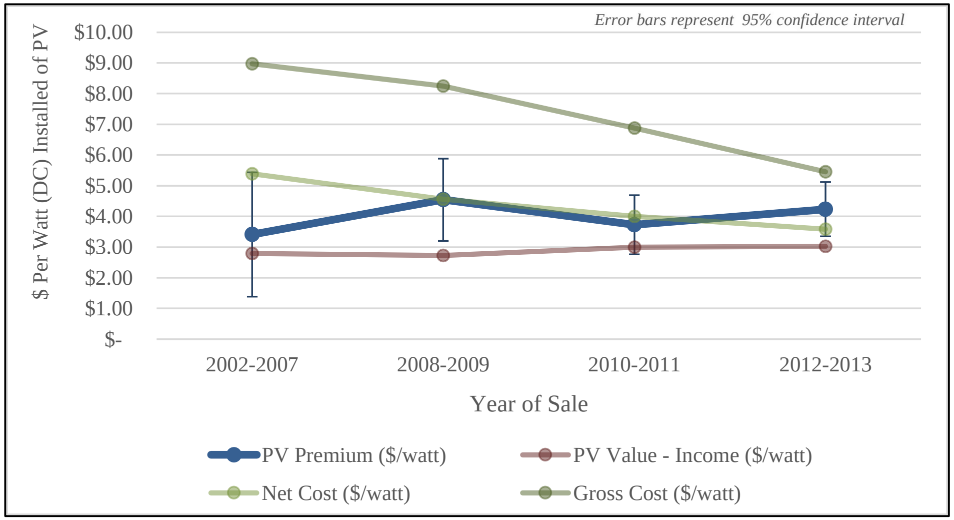
Current 2015-2017 effort is surveying 1500 individuals near turbines to examine these questions and provide baseline understanding of impacts to the population

Analyses of Value of Residential Properties With Host-Owned Photovoltaics

Eight state sample of PV homes produced consistent evidence of premiums using Hedonic pricing model <u>and</u> paired sales analysis; similar to predicted income or net cost estimates (top figure)

Premiums stable over time, despite falling gross costs of solar (bottom), and apparent across all data subsets (not shown)

Analysis of TPO sales and commercial properties is forthcoming; seeking to incorporate of PV in MLSs

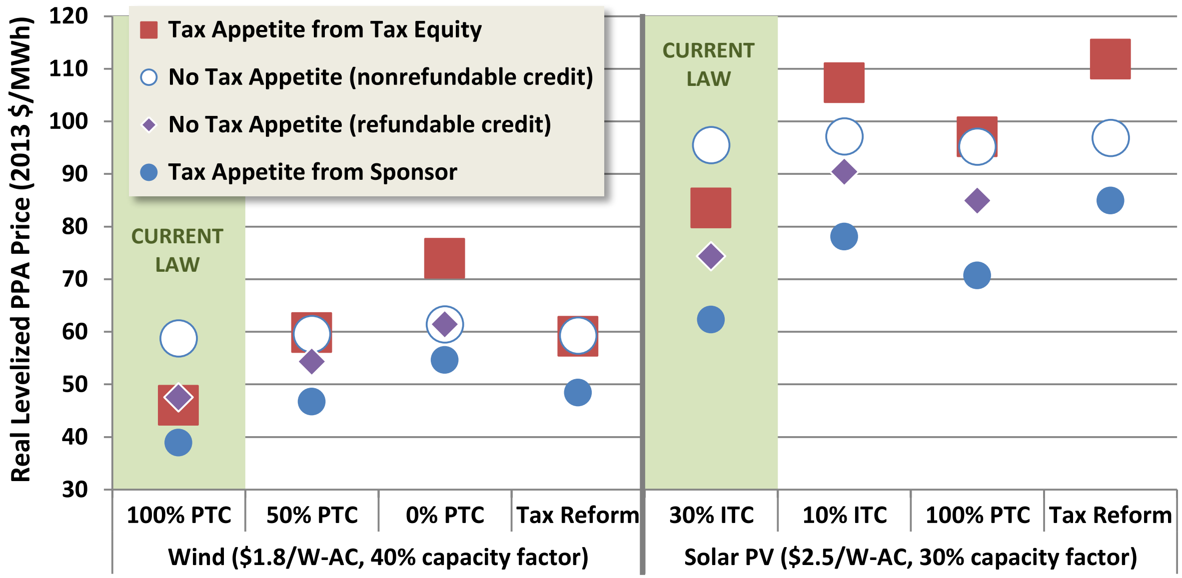


Sources: Hoen et al. LBNL Report. 2011.; Hoen et al. LBNL Report. 2013.; Hoen et al. *Contemporary Economic Policy*. 2013.; Hoen et al. LBNL Report. 2015; Adomatis and Hoen, LBNL Report. 2015; Adomatis and Hoen, *The Appraisal Journal*, 2016.

Wind/Solar Finance Work

Explores the impact of policy on project finance and LCOE

2014 work finds that third-party tax equity is likely to be displaced by debt (or other cheap capital, like yieldco equity) under most future scenarios in which ITC/PTC are phased down/out.



2015 work estimates the incremental federal tax benefits provided to TPO (vs. host-owned) residential PV, and explores how states can level the playing field were that desired.

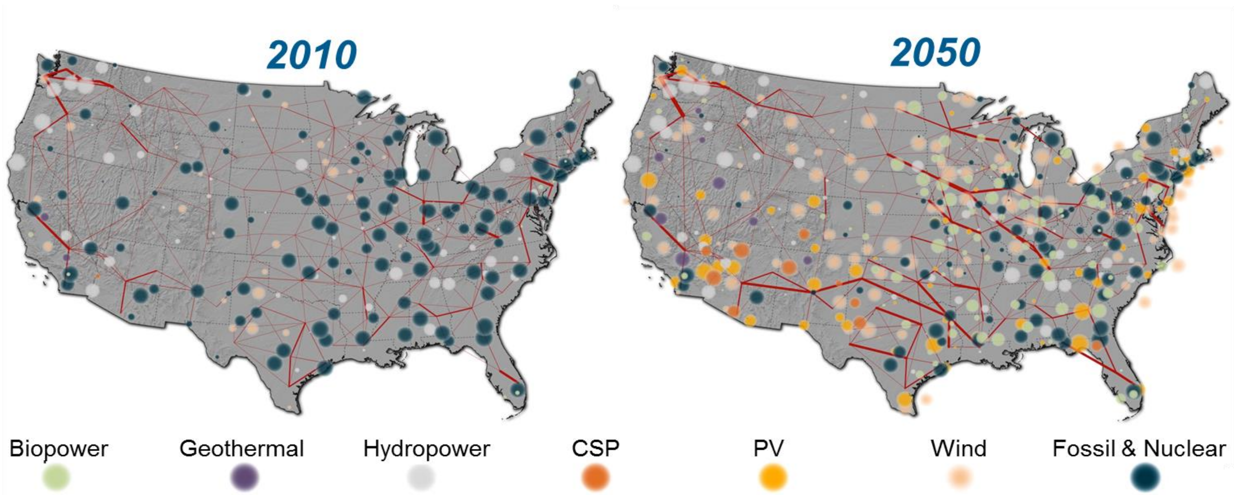
Calculation of Incremental 30% ITC/Grant Provided to TPO Systems

	Median TPO (FMV)	Median Host-Owned (Installed Price)	Difference (TPO - Host-Owned)	Incremental ITC/Grant: 30% of Difference	Incremental ITC/Grant: Applied to a 5 kW_{DC} system
	2013 $/$W_{DC}$	2013 $/$W_{DC}$	2013 $/$W_{DC}$	2013 $/$W_{DC}$	2013 $
2009	11.7	8.4	3.3	1.0	4,950
2010	9.0	7.2	1.8	0.5	2,700
2011	8.2	6.5	1.7	0.5	2,550
2012	*7.0**	5.4	1.6	0.5	2,400
2013	*6.0**	4.7	1.3	0.4	1,950

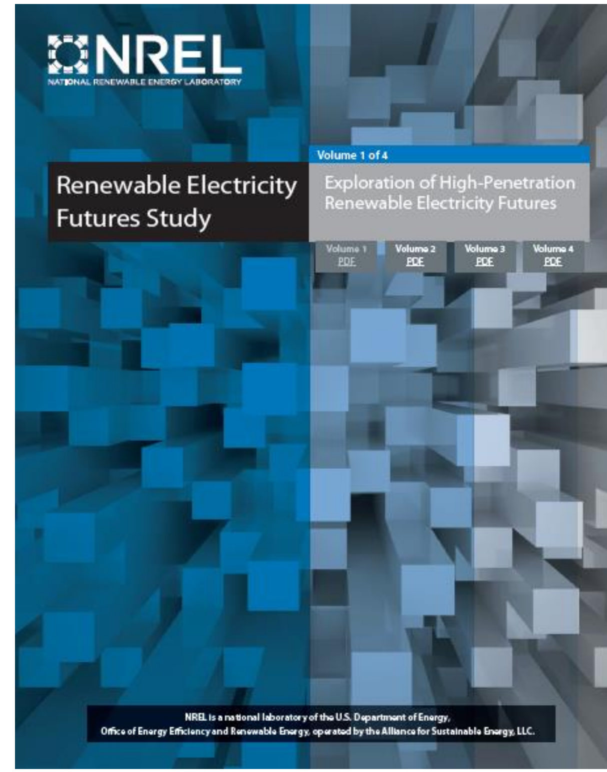
* TPO FMV and host-owned installed price data come from the *Tracking the Sun VII* (Barbose et al. 2014) data shown in Figure 1, except for in 2012 and 2013, when the TPO FMV is set to match Treasury guidance of $7/$W_{DC}$ and $6/$W_{DC}$, respectively (for reasons explained in the text).

Sources: Bolinger. LBNL Report. 2014. Bolinger. LBNL Report. 2015.

RE Futures: An Analysis of an 80% U.S. Renewable Electricity Future



Source: Renewable Electricity Futures (2012)



Other multi-party studies include: 20% Wind Energy Report (2008), Wind Vision (2015), SunShot Vision (2012, 2016), Hydropower Vision (2016); Geothermal Vision (2017); IPCC SRREN (2011), IPCC AR5 (2014)

Also published in IEEE, Applied Energy, Electricity Journal, etc.

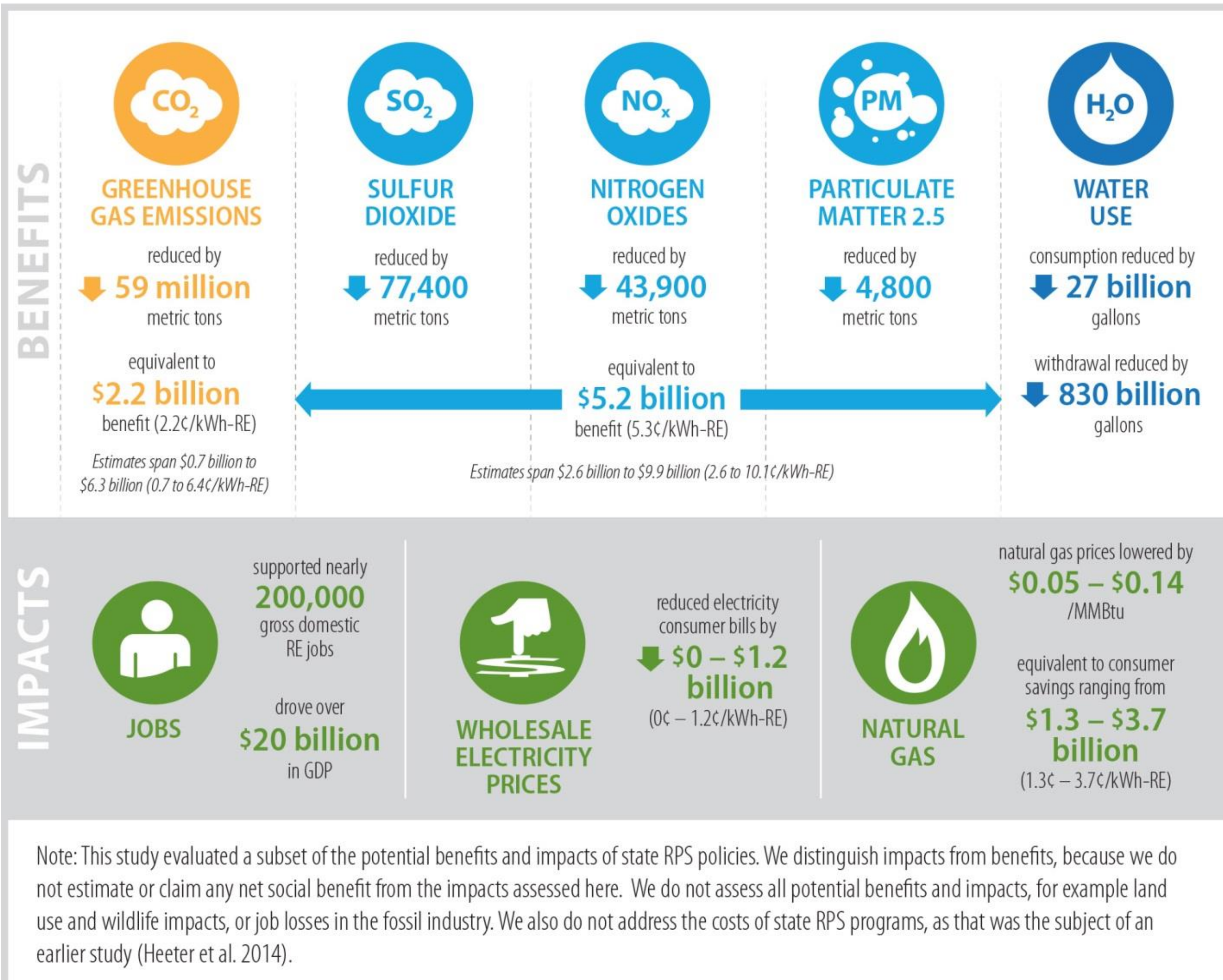
Understanding the Benefits and Impacts of Renewable Energy

LBNL (and NREL) has developed methods to assess in physical and, where feasible, monetary terms the “secondary” benefits/impacts of renewable energy.

First applied in Wind Vision; now being applied in many other high-penetration RE studies and also to assess state-level RPS policies.

- Greenhouse gas emissions reduction
- Air pollution impacts
- Water use reduction
- Energy diversity and risk reduction
- Workforce and economic development impacts

State Renewables Portfolio Standards: Cost, Benefits, and Impacts



Sources: Barbose et al. *Renewable and Sustainable Energy Reviews* 2015; Wiser et al. LBNL report 2016; Barbose et al. LBNL report 2016; Barbose et al. *Energy Policy* 2016 (submitted).

RPS compliance costs were ~$2.1B in 2013

Sizable uncertainty, but benefits of GHG and air pollution reduction total ~$7.4B in 2013 under central estimates

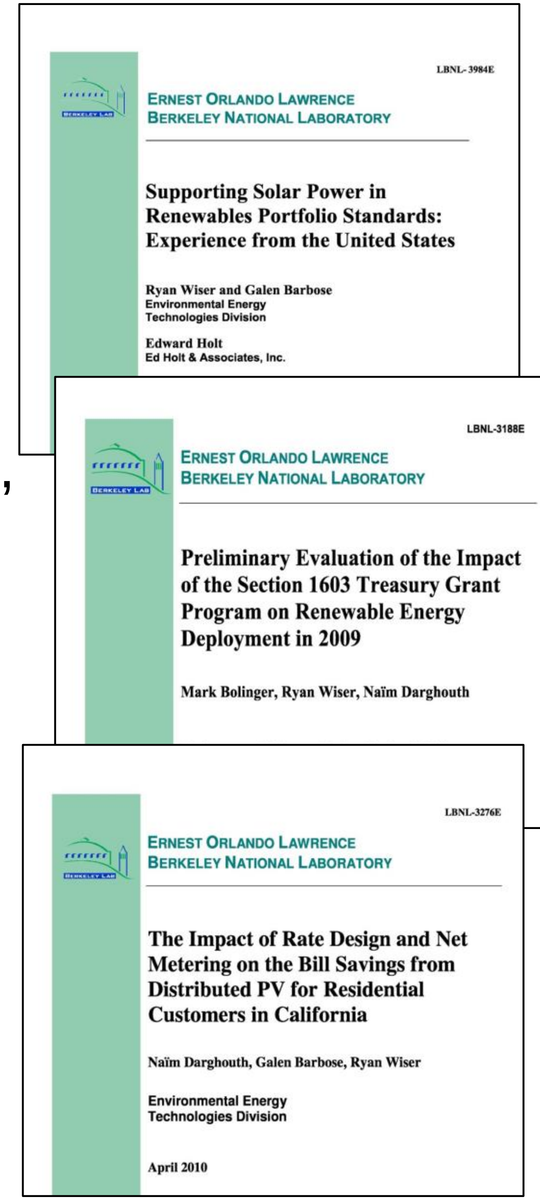
Work underway in 2016-17 evaluates *future* costs, benefits, and impacts

Section 4. Direct State and Federal Policy Assistance

Providing policy-relevant analysis to directly inform state and federal decision making

State and Federal RE Policy Assistance

- LBNL conducts technical analysis & advises states and the federal government on renewable energy program design → typically linked to our research, as presented earlier
- Areas include: RPS, net metering/rate design, utility business models, RE valuation / integration, tax policy, financing & financial incentives, etc.
- Examples:
  - Kentucky value of solar energy
  - Arkansas RPS/CES scoping
  - Nevada PV-DG net metering C/B analysis
  - NPCC utility resource planning
- Regularly brief policy-makers on our work: e.g., NGA, NCSL, NARUC, CESA



LBNL-3984E

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Supporting Solar Power in Renewables Portfolio Standards: Experience from the United States

Ryan Wiser and Galen Barbose
Environmental Energy Technologies Division

Edward Holt
Ed Holt & Associates, Inc.

LBNL-3188E

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

Preliminary Evaluation of the Impact of the Section 1603 Treasury Grant Program on Renewable Energy Deployment in 2009

Mark Bolinger, Ryan Wiser, Naïm Darghouth

LBNL-3276E

ERNEST ORLANDO LAWRENCE BERKELEY NATIONAL LABORATORY

The Impact of Rate Design and Net Metering on the Bill Savings from Distributed PV for Residential Customers in California

Naïm Darghouth, Galen Barbose, Ryan Wiser

Environmental Energy Technologies Division

April 2010

Sources: Bolinger et al. *Energy Policy*. 2010.; Darghouth et al. *Energy Policy*. 2011. ; Wiser et al. *Energy Policy*. 2011

Conclusions

The Value of and Audiences for Our Work Are Multifaceted

- Diverse product types
  - Direct assistance to policymakers, on request
  - Foundational data collection and dissemination
  - Rigorous analysis of underlying data
  - Other selected research efforts where a need exists
- Diverse audiences: from international climate negotiators to local permitting authorities, and from utility managers and renewable energy stakeholders to academics
- Three over-riding goals
  - Stay nimble to be responsive to emerging issues
  - Maintain a mix of "foundational" and "intellectual" work
  - Emphasize rigor, objectivity, and independence

Questions?

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To hear more about our work:

- visit our homepage: http://emp.lbl.gov
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